Docket No.: 4932
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Filed: January 9, 2006

TRANSLATOR'S DECLARATION

I, Walter F. Fasse, having an office at: 60G Main Road North,
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solemnly declare:

that I am fully conversant and knowledgeable in the German language to fluently read, write, and speak it, I am also fully conversant and knowledgeable in the English language;

that I have, to the best of my ability, prepared the attached accurate, complete and literal translation of:

PCT International Application PCT/DE2004/001412, filed on July 2, 2004

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Date: January 9, 2006

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ACCURATE LITERAL TRANSLATION OF PCT INTERNATIONAL APPLICATION PCT/DE2004/001412 AS FILED ON 2 JULY 2004

Method and Device for Milling Freeform Surfaces

The invention relates to a method for the milling of freeform surfaces according to the preamble of the patent claim 1. Moreover, the invention relates to an apparatus for the milling of freeform surfaces according to the preamble of the patent claim 8.

The present invention relates to the field of milling technology, especially the HSC milling (High Speed Cutting milling), which is also designated as HPC milling (High Performance Cutting milling).

In the milling of freeform surfaces, a tool, a so-called miller, is moved relative to the workpiece. The motion of the tool relative to the workpiece is described by tool paths or milling paths. According to the prior art, such tool paths or milling paths are defined or programmed via support points or check points or way points. In order to ensure the best possible quality of the freeform surface to be milled, the spacing distance between the individual support points must be as small as possible. With a small spacing distance of the support points, the number of the support points per milling path is large. The greater the number of the support points, the greater is also the data volume to be processed by a control arrangement

of the milling machine. The greater the data volume, accordingly the greater are the demands on the processing speed of the control arrangement of the milling machine. If, namely, the processing speed of the control arrangement is limited, then the case can certainly arise, that with a too-large number of the support points and therewith a too-high data quantity that is to be processed, the control arrangement of the milling machine can no longer process the arising data quantity in such a time window so that a continuous motion of the milling tool is ensured. In this case, the motion of the milling tool relative to the workpiece proceeds in a jerky or jump-like manner. This must be avoided for quality reasons. However, the larger that the spacing distance of the support points is selected, the more faceted the freeform surface that is to be milled becomes. Therefore quality problems arise also with a reduction of the support point number and thus with an increase of the support point spacing distance.

Starting from this point, the underlying problem on which the present invention is based, is to provide a novel method for the milling of freeform surfaces as well as a corresponding apparatus.

This problem is solved in that the above initially mentioned method for the milling of freeform surfaces is further developed by the features of the characterizing part of the patent claim 1.

According to the invention, the support points of the or each tool path are defined either in workpiece coordinates or in machine coordinates. Thereafter, at least one spline is produced or generated as a function of the support points for each tool path. The or each spline is output to a control arrangement of the milling machine, whereby the control arrangement controls the motion of the tool along the or each tool path on the basis of the or each spline.

Through the present invention, the data volume to be processed by the control arrangement of the milling machine is also reduced even when a small support point spacing distance and therewith a high number of support points is selected in the programming of the or each tool path. Namely, splines are laid through the support points. The number of the splines corresponds to the number of coordinates per support point. As splines comprise an always-continuous course or progression, a quality improvement also arises for the freeform surface that is to be milled.

The apparatus according to the invention is characterized by the features of the patent claim 8.

Preferred further embodiments of the invention arise from the dependent claims and the following description.

Example embodiments of the invention, without being limited hereto, are explained in further detail in connection with the drawing. In the drawing:

Fig. 1 shows a strongly schematized illustration of a tool path defined via support points in the sense of the prior art;

Fig. 2 shows a strongly schematized illustration of a tool path defined via support points together with a spline laid along the support points in the sense of the invention; and

Fig. 3 shows a strongly schematized block circuit diagram of an inventive apparatus for the milling of freeform surfaces.

In the following, the present invention will be explained in greater detail with reference to the figures. Before the details of the inventive method as well as the inventive apparatus will be explained, however, in the following a few terms will be defined, to which reference will be made later.

In the milling machining or processing of a workpiece that is to be machined, a desired three-dimensional geometry is to be established on the surface of the workpiece. This desired three-dimensional geometry on the surface of the workpiece is also designated or referred to as a freeform surface.

The milling machining or processing of a workpiece for the formation of a defined three-dimensional freeform surface takes place with the aid of a so-called 5-axis milling. In the 5-axis

milling, a tool, a so-called miller, can be moved in five axes relative to the workpiece that is to be machined. Three axes serve for the linear relative motion of the tool relative to the workpiece, so that each point in space can be reached. In addition to this linear motion along the so-called linear axes, the tool is also movable about a pivot axis as well as a tilt axis for the realization of undercuts. Rotational motions of the tool are made possible along the pivot axis as well as the tilt axis. Hereby it is possible, that all points in space can be reached without collision. The pivot axis as well as the tilt axis are often generally also designated as round or circular axes.

For the machining of the workpiece, the tool or the miller is moved relative to the workpiece. The motion of the tool or miller relative to the workpiece is described by tool paths or milling paths. The tool paths or milling paths describe the position of a tool tip or a tool reference point relative to the workpiece. The tool paths are defined in a CAD/CAM system in the form of support points or check points or way points.

Beginning from the tool tip or from the tool reference point, a vector extends along a tool axis or a tool shaft of the tool or miller. This vector along the tool axis beginning from the tool tip in the direction of the tool shaft is referred to as a tool vector.

Fig. 1 shows, strongly schematized, the manner of proceeding in the programming of tool paths or milling paths in the sense of the prior art. Thus, Fig. 1 shows a contour 10 to be milled, of a freeform surface or of a workpiece. In order to produce this freeform surface or the contour 10, a miller must be moved relative to the workpiece. The tool path of the miller is defined via support points 11, whereby the support points 11 lie within tolerance limits 12, 13 for the contour 10. According to the prior art, the support points 11 are defined in a programming arrangement embodied as a CAD/CAM system. According to the prior art, the CAD/CAM system outputs the tool path or milling path 14, which is formed by a linear connection between neighboring support points 11, in the form of linear records or data sets. These linear records are then further processed according to the prior art by a control arrangement of a milling machine.

Fig. 2 elucidates the inventive method for the milling of freeform surfaces. Fig. 2 thus once again shows a contour 15 of a freeform surface to be milled. In the sense of the invention, support points 16 for the tool path are now defined or programmed, whereby the support points are defined either in workpiece coordinates or in machine coordinates. In that regard, the support points 16 are once again defined within tolerance limits 17, 18 for the contour 15 of the freeform surface to be milled. In the sense of the invention, at least one spline 19 is generated dependent on the support points 16 for the tool path. The spline 19 is illustrated with a dashed line in Fig. 2. From Fig. 2 it follows directly that the spline 19 has an overall

continuous course or progression, and thus comprises absolutely no discontinuity points, in contrast to a linear connection 20 between the individual support points 16. The or each spline 19 is then output to a control arrangement of the milling machine. The motion of the tool or miller along the or each tool path is controlled dependent on the or each spline.

It lies within the sense or scope of the present invention, to define the support points 16 for the or each tool path either in workpiece coordinates or in machine coordinates. If the definition of the support points takes place in workpiece coordinates, then six coordinates are specified or fixed for each support point. On the other hand, if the definition of the support points 16 takes place in machine coordinates, then five coordinates are defined for each support point.

For all coordinates of the support points, a spline is now respectively specified or fixed for a tool path that has been programmed via support points 16 in a CAD/CAM apparatus. In the case in which the support points are defined in workpiece coordinates, a total of six splines are produced for each tool path, because six coordinates are necessary per support point for a definition of the support points in workpiece coordinates. In the case in which the support points are defined in machine coordinates, a total of five splines are produced for each tool path.

The production or generation of the splines takes place via an interpolation method that is known from the numerical mathematics. Reference is made to the relevant literature regarding the mathematical details. For the production or generation of the five or six splines per tool path it is significant that the interpolation parameters for all splines of the respective tool path are selected to be equal or the same. Accordingly, all five or six splines of a tool path are defined either over the path length or the milling time. If the interpolation parameters are the same for all splines, then the splines of a respective tool path are synchronized.

Fig. 3 shows a strongly schematized block circuit diagram of an apparatus according to the invention for the milling of freeform surfaces. In the illustrated example embodiment, the apparatus according to the invention encompasses a programming arrangement 21 for the programming of at least one tool path or milling path of a milling tool via support points. The support points are programmed either in machine coordinates or in workpiece coordinates as already mentioned above.

The first programming arrangement 21 is a CAD/CAM system. The CAD/CAM system produces or generates a so-called APT (Automatic Programming Tool) file 22, whereby an APT processor 23 produces from the APT file 22 a machine-independent control file 24 for the milling machining of the workpiece. With the aid of so-called post-processors 26, so-called control or NC files 27, which are machine-dependant, are produced from the

machine-independent control file 24. These control or NC files 27 are provided to control arrangements 28, which control the individual motion axes of the milling machine or NC machine.

Means 25 are allocated to the programming arrangement 21 in order to produce at least one spline for each tool path dependent on the support points. The production or generation of the splines for the tool paths takes place in the above described type and manner. In the example embodiment of the Fig. 3, the splines produced as a function of the support points by the means 25 are transferred to the APT processor 23, which transfers the corresponding spline data in the machine-independent control file 24 to the post-processors 26.

The post-processors 26 provide the splines in the machine-dependent control files 27 in polynomial format to the control arrangements 28. The control arrangements 28 control the motion of the tool along the tool paths on the basis of the corresponding splines. Through the provision of the splines in polynomial format it is ensured that the control arrangements 28 of the milling machine or NC machine can further process the splines without problems and can use the splines for the control of the milling tool.

With the aid of the inventive method as well as the inventive apparatus, the milling of freeform surfaces can be considerably improved. The data volume to be processed by the milling machine is considerably reduced. The splines ensure curve-continuous

tool paths, whereby the surface quality of the freeform surfaces to be produced can be considerably improved. The milling machine is less strongly excited into vibrations, and therefore also the milling tools are subjected to a low wear.

The inventive apparatus as well as the inventive method are especially suitable for the milling machining of rotationally symmetrical gas turbine components with integral blading, that is to say so-called blisks (bladed disks) or blings (bladed rings).